"GAUSSIAN PROFILED HORN ANTENNAS"

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***Abstract.* In many different applications parameters such efficiency, gain, directivity, etc., are really critical. By using the Gaussian techniques presented here, the radiating features of existing horn antenna systems can be improved, only by adding some portion of Gaussian horn antenna at the end or designing a new horn antenna system.**

In this paper some special features of the Gaussian profiled horn antennas are presented. Furthermore, different design methods based on the Gaussian techniques are analyzed, describing the advantages of these methods versus the existing methods. Some practical examples, comparisons and measurements are also given.

I. INTRODUCTION

In most of the applications which the horn antennas are involved, parameters such diffraction, directivity, gain, side lobes, etc., become really important. These parameters are much more critical as more expensive the system is, i.e., satellite - earth links, high power applications, high frequency or wider frequency response requirements, among others.

The introduction of the Gaussian profiled horn antennas [1,2] become very useful to fight against these problems. By using these horn antennas, the matching between the waveguide and the free space is almost perfect, being the most "natural" way to match the two media. As it will be shown, when the electromagnetic fields pass through this kind of horn antenna, they become more and more independent of the waveguide structure, and, at the end of the horn, the fields are practically radiating as they would do if they were in the real free space conditions. This can be easily checked using a quite simple experiment based on cutting one of these Gaussian horn antennas at different lengths, and proving that the far field radiation pattern keeps practically unchanged despite of increasing the output radius of the horn. This experiment has been presented by the authors previously [3,4] and helps to understand the behavior of these Gaussian antennas.

Furthermore, the use of these Gaussian horn antennas to improve the far field radiation pattern of any existing conical horn antennas adding at its end some part of Gaussian profiled horn will be analyzed. The main far field radiation pattern features of the conical horn antenna will be kept reducing strongly the side-lobes as well as the cross polarization level.

Finally, the substitution of the horn system by another one based on Gaussian profiled horn antennas will be proposed and developed. The advantage of these Gaussian horn antennas to offer more freedom degrees to the designer in order to change the far field radiation pattern optimizing either the cross-polar level or side-lobe level or response in frequency, etc., will be shown.

II. EXPLANATION OF THE IDEA

The working idea of these Gaussian profiled horn antennas is really simple. It is based on the fact that the Gaussian beam modes are solutions of the paraxial wave equation in the free space [3]. Any paraxial radiation from a waveguide can be understood as an infinite summation of Gaussian beam modes, since the Gaussian beam modes are orthogonal and they are a generating basis in free space. The idea is to generate any kind of transversal field distribution with Gaussian radiation features.

It is well known that the HE_{11} circular corrugated waveguide mode has very good far field radiation pattern, with low side-lobe and low cross-polarization levels. These are mainly the reasons to refer this mode as gaussian-like mode. In fact, it is used in many applications to illuminate subreflectors or beam waveguides.

The HE_{11} mode can be represented with smooth circular waveguide modes as the combination of the TE_{11} (85%) and the TM_{11} (15%) modes with the appropriate phase shift. For many years, controlling the inner waveguide mode mixture in order to excite the HE_{11} circular corrugated waveguide mode have solved the problem of designing horn antennas. Usually, the starting field distribution is the TE_{11} circular waveguide mode in monomode conditions, and by means of one step or some slope in the horn radius, some portion of TM_{11} is excited until the appropriate relation between both modes with the adequate phase shift is obtained. This technique has been used for many authors during years resulting in many different publications about conical horn antennas [5,6,7].

This technique, used in non-oversized horns, has been applied also to oversized problems, using longer conical tapers in order to achieve at the end the appropriate mode mixture (85%-15%). To get this mode mixture with some specific radiating features, two main parameters have to be taken into account: the output radius and the horn length. The coupling between waveguide modes is directly related with the slope deformation of the waveguide. This means, for a given output radius (determination of the desired beam diffraction or beam width) changing the length of the conical horn (playing with the slope since the input radius is fixed) the mode mixture with the appropriate side-lobe level, or the minimum cross-polar level can be selected, if this is possible.

By using Gaussian profiled horn antennas, the different parameters such as beam diffraction, bandwidth, side-lobe and cross-polar levels, directivity, gain, efficiency, and others, can be optimized because of the higher number of freedom degrees of our system.

In order to show how all this is really possible, the first step is to define the simpler case, the single Gaussian profiled horn antenna. The idea consists on deforming the waveguide following the equation which defines the general Gaussian expansion,

$$\varpi(z) = \varpi_0 \sqrt{1+\left(\frac{2z}{k\varpi_0^2}\right)^2} \quad \Rightarrow \quad R(z) = r_0 \sqrt{1+\left(\frac{2z}{k\varpi_0^2}\right)^2} \qquad (1)$$

replacing the *$\varpi(z)$* Gaussian beam expansion (decay of *1/e* of the fields curve) by the more general expression of *$R(z)$* (horn radius along *z*), and ϖ_0 (the beam waist value) factor by r_0 (the input radius).

The input field distribution could be any field distribution with a controlled diffraction. In principle, any waveguide mode or mode mixture with low field levels close to the waveguide metallic structure are suitable to feed Gaussian profiled horn antennas. The scattered fields will have basically the same transversal distribution in amplitude but with Gaussian expansion properties.

For instance, if the TE_{01} circular smooth waveguide mode is used to feed the Gaussian horn antenna, the output will be a hollow beam azimuthally polarized expanding its width as a Gaussian structure [8].

To properly excite the fundamental Gaussian beam, something like the HE_{11} mode as input and a corrugated circular waveguide have to be used. Working under non-oversized conditions, the excitation has to be the TE_{11} mode and an impedance matching between the smooth monomode waveguide and the corrugated waveguide of the horn has to be included. In both cases, the concept of Gaussian profiled horn antennas can be successfully applied [9,10,11,12].

III. Gaussian Antennas

This idea to use Gaussian profiled horn antennas to generate Gaussian structures can be applied with any kind of waveguide sections. In this paper, only the circular waveguides have been analyzed, but similar conclusions can be obtained for rectangular, square or arbitrary sections. In any case, two different types of Gaussian profiled horn antennas, depending of the oversizing conditions, can be consider,

- *multimode conditions* [3][9], where having a horn antenna or antenna-converter already designed the radiation features by cascading some part of Gaussian profiled horn can be improved.
- *monomode conditions*, starting from a monomode waveguide. In this case, an impedance adapter is needed at the beginning of the component, in order to match properly the smooth monomode circular waveguide with the corrugated one. Starting from the fundamental smooth circular waveguide mode, TE_{11}, there are two possibilities,
  a) generate something-like HE_{11} corrugated waveguide mode [10] suitable to illuminate some mirror system (figure 1.a), or
  b) generate directly one fundamental Gaussian beam mode [11,12] (figure 1.b).

IV. Measurements

By using these techniques, the microwave and millimeter group of the *Universidad Pública de Navarra* have designed a horn antenna that it will be on board the next HISPASAT 1C satellite to be launched in the next future. The development of this antenna in particular has been held by a collaboration between the Spanish firm *CASA* and the *Universidad Pública de Navarra*.

The final Gaussian profiled horn antenna besides fitting all the electromagnetic requirements for the particular application, had a smaller output radius and was shorter than a conical horn antenna, reducing the total weight of the horn. A picture of the horn antenna, figure 2, and the comparison between simulations and measurements at the frequency of 11.7 GHz is presented in figure 3. The specifications were fixed about the gain of the final antenna system, constant taper in the whole frequency band, maximum illumination angle of 18 degrees with a maximum level at this point of -20 dB in order to avoid diffraction on mirror edges, reflection and cross polarization levels.

V. CONCLUSIONS

In this paper the main features of the Gaussian profiled horn antennas have been summarized. The fundamental idea of the Gaussian antennas and a particular design were presented. Most of the existing horn antenna systems can be improved by adding some portion of Gaussian profiled horn or redesigning fully the antenna system with Gaussian techniques. This improvement can be in electromagnetic parameters (efficiency, gain, directivity, etc.) and even in geometrical parameters (length, output radius, weight, etc.) as it have been shown with the measurements presented in this paper.

To conclude the paper, we would like to remark the fact that the Gaussian theory can be applied to any different waveguide technology, this means, that it is possible to apply this technique to rectangular, squared, ellipsoidal waveguide sections, and the improvement in the antenna parameters will be considerable.

VI. REFERENCES

[1] Spanish Patent P.9501922, "Horn Antenna Mode Converter from Waveguide Modes to Gaussian Structures", Authors: Carlos Del Río, Ramón Gonzalo, Mario Sorolla y Manfred Thumm, 25/09/1995.

[2] Spanish Patent P.9601636, "Mode converter: from the TE11 monomode circular waveguide mode to the HE11 corrugated circular waveguide mode", Authors: Carlos Del Río, Ramón Gonzalo, y Mario Sorolla, 11/07/1996.

[3] Del Río C., Gonzalo R. and Sorolla M., "High Purity Gaussian Beam Excitation by Optimal Horn Antenna", Proc. *Int. Symposium on Antennas and Propagation*, Chiba, Japan, September 1996.

[4] Del Rio, C., Teniente, J., Gonzalo, R. y Sorolla, M., "On the Determination of the Phase Center of Gaussian Horn Antennas". Proc. *2nd Workshop on Millimeter Wave Antenna Technology and Antenna Measurements*. Millilab. Espoo (Finland), May 1998.

[5] Potter, P. D., "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths", *Microwave J.*, vol. VI, June 1963, pp. 71-78.

[6] Olver, A.D., Clarricoats, P.J.B., Kishk, A.A. and Shafai, L., "Microwave Horns and Feeds", *IEE Electromagnetic Waves Series 39*, Chap. 6, 7, 8 and 9, IEEE Press 1994.

[7] Clarricoats, *P.J.B. and Olver, A.D., "Corrugated Horns for Microwave Antennas", IEE Electromagnetics Waves Series 18, Chap. 5, 6 and 7, Peter Peregrinus*, 1984.

[8] Del Río, C., Gonzalo, R., Sorolla, M. and Thumm,. M., "Optimal Horn Antenna to Excite High Order Gaussian Beam Modes from TE_{om} Smooth Circular Waveguide Modes*". To be published soon in Trans. On Antennas and Propagation*, 1999.

[9] Gonzalo R., Del Río C., Teniente J. and Sorolla M., "Optimal Horn Antenna Design to excite High Purity Gaussian Beam using Overmoded Waveguides", Proc. *21st. International Conference on Infrared and Millimeter Waves*, BTh3, Berlín, July 1996.

[10] Gonzalo R., Del Río C. and Sorolla M., "Generation of the HE_{11} Mode from Monomode Smooth Circular Waveguide", Proc. *21st. International Conference on Infrared and Millimeter Waves, BTh8*, Berlín, July 1996.

[11] Gonzalo, R., Teniente, J. y Del Río, C., "A novel and efficient corrugated feeder for reflector antennas", *IEEE-AP-S International Symposium and URSI Radio Science Meeting*, Montreal, Canada, Julio 1997.

[12] Gonzalo, R., Marti, J., Teniente, J., del Rio, C. y Sorolla, M., "Measurement of a New Gaussian Profiled Corrugated Horn Antenna for Millimeter Wave Applications". Proceedings of the *U.R.S.I. AP-S Intenatinal Symposium*. Atlanta (USA), Junio 1998.

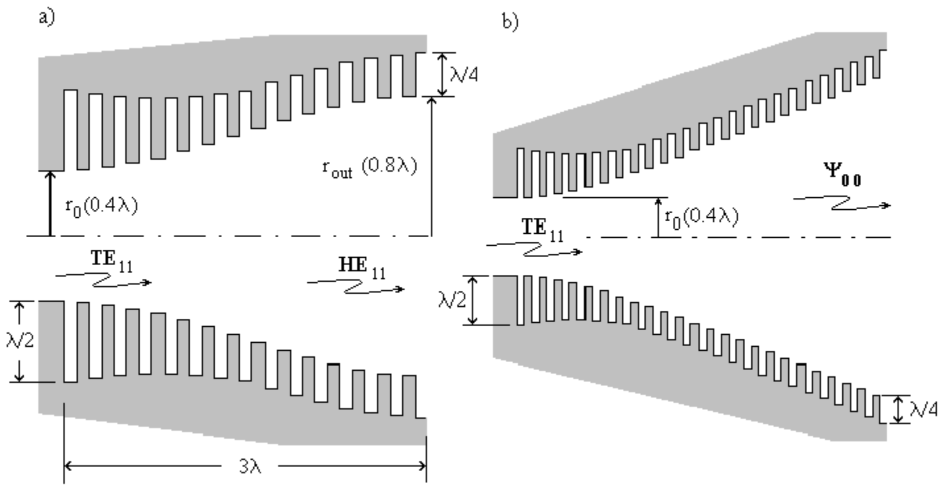

Figure 1: Different examples of Gaussian horn antennas: a).- profile of a TE_{11}-HE_{11} mode antenna-converter, b).- profile of Gaussian beam mode excitation antenna from circular monomode waveguide (TE_{11} mode).

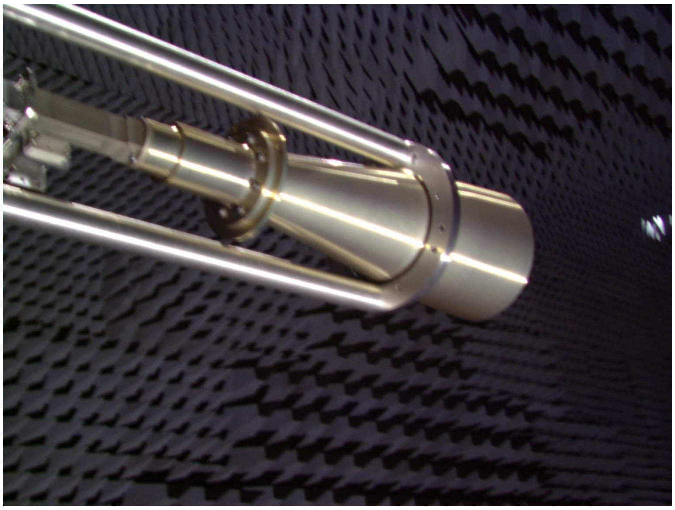

Figure 2.- Picture of the Gaussian horn antenna to be boarded in the HISPASAT 1C, photograph courtesy of CAS.A.

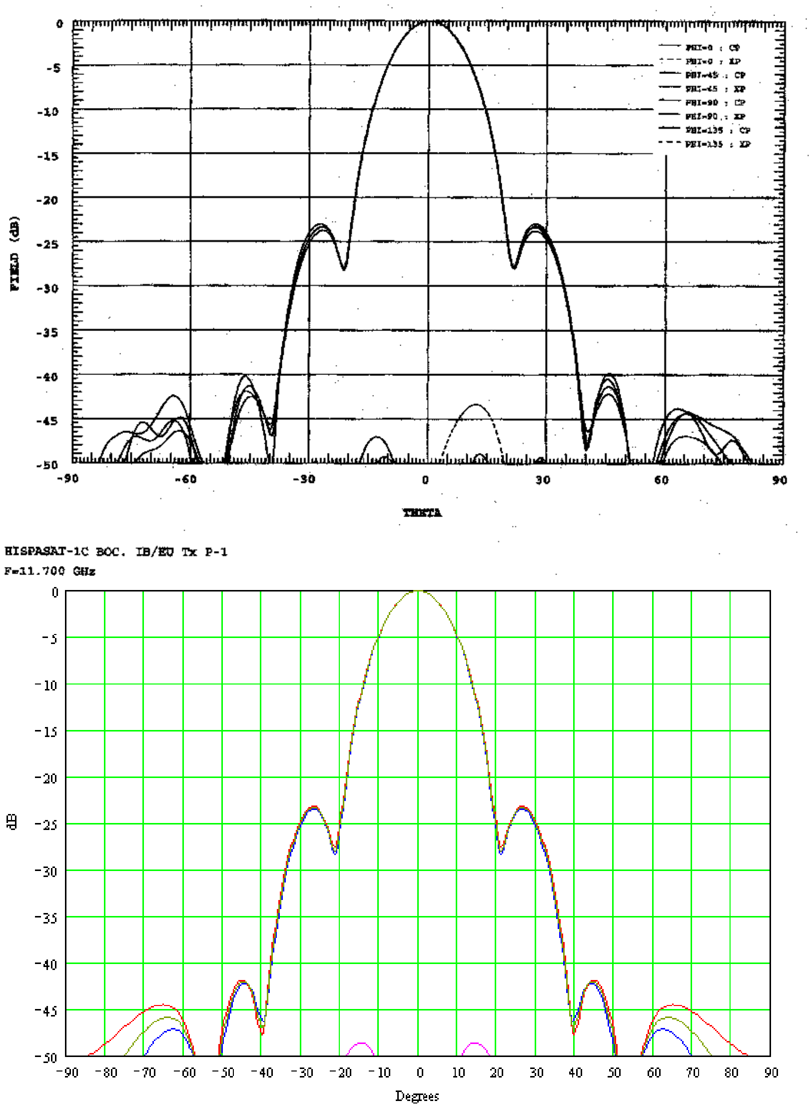

Figure 3.- Far field pattern, measured top and simulated bottom, of the Gaussian profiled horn antenna to be boarded in the HISPASAT 1C. (Measurements provided by CAS.A.)